24 Gauge Mediation: Part II

24.1 The μ Problem

Recall that in order to obtain a viable mass spectrum in the MSSM, we needed μ and b terms

$$W = \mu H_u H_d \tag{24.1}$$
$$V = b H_u H_d \tag{24.2}$$

with

$$b \sim \mu^2 \tag{24.3}$$

In gauge mediated models we need

$$\mu \sim \frac{1}{16\pi^2}\frac{F}{M} \tag{24.4}$$

If we introduce a coupling to the SUSY breaking field

$$W = \lambda X H_u H_d \tag{24.5}$$
$$\tag{24.6}$$

we get

$$\begin{aligned} \mu &= \lambda M && (24.7)\\ b &= \lambda F \sim 16\pi^2\mu^2 && (24.8) \end{aligned}$$

A more indirect coupling

$$\begin{aligned} W = X(\lambda_1\phi_1\overline{\phi}_1 + \lambda_2\phi_2\overline{\phi}_2)\\ \lambda H_u\phi_1\phi_2 + \overline{\lambda} H_d\overline{\phi_1\phi_2} && (24.9)\\ && (24.10) \end{aligned}$$

yields a one-loop correction to effective Lagrangian:

$$\Delta\mathcal{L} = \int d^4\theta \frac{\lambda\overline{\lambda}}{16\pi^2} f(\lambda_1/\lambda_2) H_u H_d \frac{X}{X^\dagger} \tag{24.11}$$

This gives the same ratio for b/μ^2. The correct ratio can be arranged with the introduction of two additional singlet fields S and N:

$$W = S(\lambda_1 H_u H_d + \lambda_2 N^2 + \lambda\phi\overline{\phi} - M_N^2) + X\phi\overline{\phi} \tag{24.12}$$

then

$$\mu = \lambda_1 \langle S \rangle \tag{24.13}$$
$$b = \lambda_1 F_S \tag{24.14}$$

A VEV for S is generated at one loop

$$\langle S \rangle \sim \frac{1}{16\pi^2} \frac{F_X^2}{M M_N^2} \tag{24.15}$$

but F_S is only generated at two loops:

$$F_S \sim \frac{1}{(16\pi^2)^2} \frac{F_X^2}{M^2} \sim \frac{1}{16\pi^2} \mu \frac{M_N^2}{M} \tag{24.16}$$

So $b \sim \mu^2$ if $M_N^2 \sim F_X$. So elaborate models seem to be needed to solve the μ problem in the gauge mediated scenario.

24.2 Direct Gauge Mediation

A more elegant (and more difficult from the model building view point) approach to gauge mediation is direct gauge mediation where the fields that break SUSY have SM gauge couplings. Consider

	$SU(5)_1$	$SU(5)_2$	$SU(5)$
X	$\mathbf{1}$	$\square$	$\overline{\square}$
ϕ	$\overline{\square}$	$\mathbf{1}$	$\square$
$\overline{\phi}$	$\square$	$\overline{\square}$	$\mathbf{1}$

with a superpotential

$$W = X^i_j \overline{\phi}^j \phi_i \ . \tag{24.17}$$

We can weakly gauge the global $SU(5)$ with the SM gauge groups. For large $X \gg \Lambda_1, \Lambda_2$, ϕ and $\overline{\phi}$ get a mass and

$$\Lambda_{\text{eff}}^{3\cdot 5} = \Lambda_1^{3\cdot 5-5} \, (\lambda X)^5 \tag{24.18}$$
$$W_{\text{eff}} = \Lambda_{\text{eff}}^3 \sim \lambda X \Lambda_1^2 \tag{24.19}$$

so SUSY is broken. Adjusting λ we can find a local minimum where $\gamma = 0$. For $\langle X \rangle > 10^{14}$ GeV, the Landau pole for λ is above the Planck scale. The problem is that heavy gauge boson messengers can give negative contributions to squark and slepton squared masses. In the general case where two gauge groups break down to the SM gauge groups

$$G \times H \to SU(3)_c \times SU(2)_L \times U(1)_Y \tag{24.20}$$

and

$$\frac{1}{\alpha(M)} = \frac{1}{\alpha_G(M)} + \frac{1}{\alpha_H(M)} \ , \tag{24.21}$$

$$\langle X \rangle = M + \theta^2 F \tag{24.22}$$

Analytic continuation in superspace gives

$$M_\lambda = \frac{\alpha(\mu)}{4\pi}(b - b_H - b_G)\frac{F}{M} \tag{24.23}$$

and

$$\begin{aligned} m_Q^2 \ &= \ 2C_2(r)\frac{\alpha(\mu)^2}{(16\pi^2)^2}\left(\frac{F}{M}\right)^2 \\ &\quad \left[(b + (R^2 - 2)b_H - 2b_G)\xi^2 + \frac{b - b_H - b_G}{b}(1 - \xi^2)\right] \ , \end{aligned} \tag{24.24}$$

where

$$\xi \ = \ \frac{\alpha(M)}{\alpha(\mu)} \tag{24.25}$$

$$R \ = \ \frac{\alpha_H(M)}{\alpha(M)} \ . \tag{24.26}$$

This typically gives a negative mass squared for right-handed sleptons. Another danger for direct mediation models is if not all the messengers are heavy. Then the two loop RG gives:

$$\mu\frac{d}{d\mu}m_Q^2 \propto g^2\left[cg^2\mathrm{Tr}\left((-1)^{2F}m_{ij}^2\right) - M_\lambda^2\right] \tag{24.27}$$

which can drive the mass squared negative. If the gluino is heavy, then again it is the sleptons that receive dangerous contributions.

24.3 Single Sector Models

Another appealing approach to gauge mediation is to have the strong dynamics that break SUSY also produce composite MSSM particles. Consider:

	$SU(k)$	$SO(10)$	$SU(10)$	$SU(2)$
Q	$\square$	$\square$	$\mathbf{1}$	$\mathbf{1}$
L	$\overline{\square}$	$\mathbf{1}$	$\square$	$\mathbf{1}$
$\overline{U}$	$\mathbf{1}$	$\square$	$\overline{\square}$	$\mathbf{1}$
S	$\mathbf{1}$	$\mathbf{16}$	$\mathbf{1}$	$\square$

with a superpotential

$$W = \lambda Q L \overline{U} \ . \tag{24.28}$$

This is a baryon runaway model For large $\det\overline{U} \gg \Lambda_{10}$

$$W\text{eff} \sim \overline{U}^{10/k} \tag{24.29}$$

while for small $\det\overline{U} \ll \Lambda_{10}$

$$W\text{eff} \sim \overline{U}^{10(1-\gamma)/k} \tag{24.30}$$

For $k > 10(1-\gamma)$ SUSY is broken. There are two composite generations corresponding to the spinor S. The composite squarks and sleptons have masses of order

$$m_{\text{comp}} \approx \frac{F}{\overline{\overline{U}}} \ . \tag{24.31}$$

This can be thought of as gauge mediation via the strong $SO(10)$ interactions. The global $SU(2)$ symmetry enforces a degeneracy that suppresses FCNC's. The composite fermions can only get couplings to the Higgs fields from higher dimension operators, so they are light. The fundamental gauginos and third generation scalars get masses from gauge mediation.

References

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